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SIMNET-BASED TESTS OF ANTIHELICOPTER MINES

R. E. Schwartz, *Project Leader*

January 1994

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This report describes a series of SIMNET Semi-automated Forces armor engagements in which antihelicopter mines are deployed. The impact of two types of antihelicopter mines on armor exchange ratios and other combat measures is presented. Learning effects are analyzed for both types of mine. Antihelicopter mines can have a significant effect on small unit engagements when used in conjunction with an effective air defense system. Direct fire and sublet launched antihelicopter mines, when properly deployed, are capable of depriving attack helicopters safe ingress routes and firing positions.

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PREFACE

This project has been conducted by the Institute for Defense Analyses (IDA) under a task from the Advanced Research Projects Agency (ARPA), Advanced Systems Technology Office (Advanced Land Systems).[1]

Mr. Harry L. Reed and Mr. Clifford J. Landry made valuable contributions to this task. Each played a major role in the simulated test exercises whose results are reported in this paper.

The IDA Technical Review Committee--Ms. Julia J. Loughran, Mr. Warren K. Olson, Dr. Maile E. Smith, and Ms. Marchelle M. Stahl--and its chairman, Dr. David L. Randall, Director of the Systems Evaluation Division, made a number of helpful suggestions.

1 Armor/Antiarmor System Concepts, Task A-117, Amendment Number 4, dated December 30, 1991.

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I. INTRODUCTION AND SUMMARY

A. PURPOSE

This report describes a series of SIMNET-based tests using the Smart-Mine Simulator (SMS). These tests took place at the Institute for Defense Analyses (IDA) from late March through early July 1993 and were conducted using SIMNET Semi-Automated Forces (SAF), version 4.3.3. All tests were free play exercises in which a Blue "commander" competed against an Opposition Force (OPFOR) "commander" by issuing maneuver commands to SAF units through Silicon Graphics workstations. Test trials differed by scenario type and the number and type of antihelicopter mines (AHMs) deployed [direct fire (DF) or sublet launched (SL)]. The intent of the testing was to explore the potential combat utility of smart AHMs in small unit engagements, gain insight into deployment strategies, and enhance our ability to use SIMNET as an analytic tool.

B. OVERVIEW OF TESTS

A total of 86 tests were conducted. Each was a small armor engagement lasting between 15 and 40 minutes. Four different scenarios were used, grouped into two pairs. Each pair consisted of an offensive scenario, in which Blue forces attacked OPFOR defensive positions, and a defensive scenario, in which Blue forces defended against attacking OPFOR units. All scenarios used the Hunter-Liggett terrain database and some were modeled on 1988 forward area air defense system (FAADS) exercises. One pair of scenarios used one portion of the terrain, with the positions of Blue and OPFOR reversed in the two members of the pair. The other pair reversed Blue and OPFOR positions on a different part of the terrain. As shown in Table 1, 46 offensive trials and 40 defensive trials were conducted, varying the number and type (DF or SL) of AHMs used in the test.

Table 1. Summary of Test Cases

Scenario	Number and Type of AHM					Total
	0 AHM	15 DF	25 DF	15 SL	25 SL	
Offense_1	9	5	5	4	4	27
Defense_1	3	4	4	6	5	22
Offense_2	3	4	4	3	5	19
Defense_2	4	3	4	4	3	18
Total	19	16	17	17	17	86

All attacking forces consisted of two tank platoons and two mechanized infantry platoons. All defending forces consisted of one tank platoon and one mechanized infantry platoon. In addition, the OPFOR always contained a flight of MI28 HAVOC attack helicopters. Blue always deployed one air defense artillery (ADA) vehicle and, depending on the trial being run, a supply of AHMs. These force levels, somewhat smaller than those used in the FAADS tests, were selected because they constitute a manageable load for the two SAF operators.

Helicopter flight size varied between two or three per trial: three rotary wing aircraft (RWA) were deployed in 13 offensive trials and in two defensive trials; all others used two. Average RWA deployment by trial category is shown below in Table 2.

Table 2. Average RWA Deployment

Mean RWA Deployed	0 AHM	15DF	25DF	15SL	25SL
Offense	2.3	2.2	2.3	2.4	2.2
Defense	2.0	2.0	2.0	2.1	2.1

Two types of AHMs are represented by the SMS: direct fire (DFAHM) and sublet launched (SLAHM). The DFAHM has an infra-red (IR) sensor that scans a vertical cone whose vertex lies on the ground at the mine's position and whose sides are inclined 45 degrees with respect to the horizontal. When a target is detected entering or exiting this cone, it is attacked by detonating a warhead with multiple explosively formed penetrators (EFPs). The SLAHM employs an acoustic sensor to detect the target and determine a launch direction for the sublet. The sublet contains an IR sensor and a multiple EFP warhead. Scanning of the sensor is accomplished by precession of the sublet.

The following input parameters were used for the DFAHM. The DFAHM was activated when a helicopter approached to within 250 meters. If its IR sensor detected the target, it could engage a helicopter out to a slant range of 141 meters. Given a firing, its probability of kill (or, equivalently for the analysis, of causing a mission abort) was unity.

The SLAHM was activated when a helicopter approached to within 1,000 meters. If the tracking process resulted in an estimated closest point of approach of less than the specified maximum engagement range, the sublet would be launched. If the IR sensor on the sublet detected a target, the EFP warhead could engage the target out to 152 meters slant range. Given a firing of the warhead, the probability of kill (or mission abort) was unity.

Further details on the representation of AHMs are given in Chapter II, Section A.

C. SUMMARY OF RESULTS

The specific structure of the scenarios measured the effect of AHMs when used in conjunction with a relatively invulnerable ADA vehicle with extended range capabilities. The offensive scenarios were constructed so that (on average) OPFOR armor could not overcome Blue without the assistance of RWA. Also, Blue could not defeat OPFOR armor if OPFOR RWA operated freely, or even within envelopes limited in extent by ADA. (RWA were generally forced by ADA to fly below 100 meters when in range of their targets). This "force balance" provided the setting for exploring the use of AHMs on the battlefield. Defensive scenarios were constructed by reversing the positions of Blue and OPFOR armor.

1. Effectiveness

Anti-helicopter mines were used in 67 of the 86 trials. A total of 655 DFAHMs were deployed in 33 trials and 652 SLAHMs were deployed in 34 trials. Their effect on battle outcome was measured by the difference between Blue armor losses and OPFOR armor losses for each trial category. These differences are displayed in Figure 1.

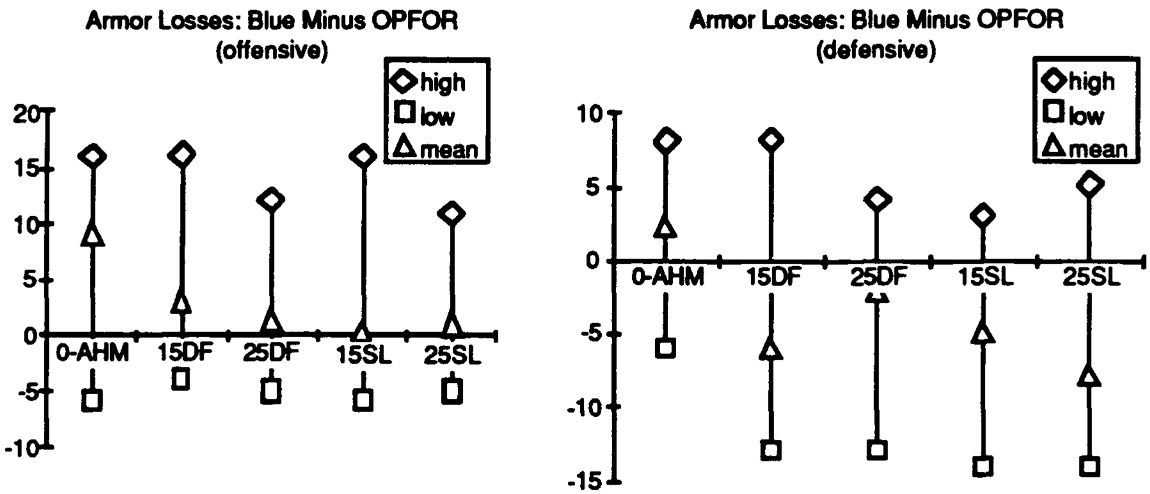

Figure 1. Difference in Armor Losses (Blue Minus OPFOR)

In the offensive scenarios, the difference between Blue and OPFOR armor losses decreased from 9.17 vehicles, on the average, when no AHMs were deployed to 1.35 vehicles when AHMs were deployed. Similarly, in defensive scenarios, the mean difference dropped from 2.3 vehicles to -5.0 vehicles per trial. Standard statistical tests indicate that the decrease in means is significant well below the 1 percent level in the

offensive scenarios and is significant at approximately the 1 percent level in the defensive scenarios. On the other hand, differences among the cases in which AHMs were deployed were not statistically significant.

Another combat measure, the mean number of RWA destroyed per trial, also reflected the utility of AHMs. When no AHMs were deployed, ADA and direct fire from Blue armor destroyed, on the average, 37 percent of the RWA force per offensive trial and 43 percent of the force per defensive trial. After AHMs were introduced, these means changed to 94 percent and 76 percent, respectively. Figure 2 displays the percentage of the RWA destroyed by AHMs and all other agents (ADA and direct fire by Blue armor).

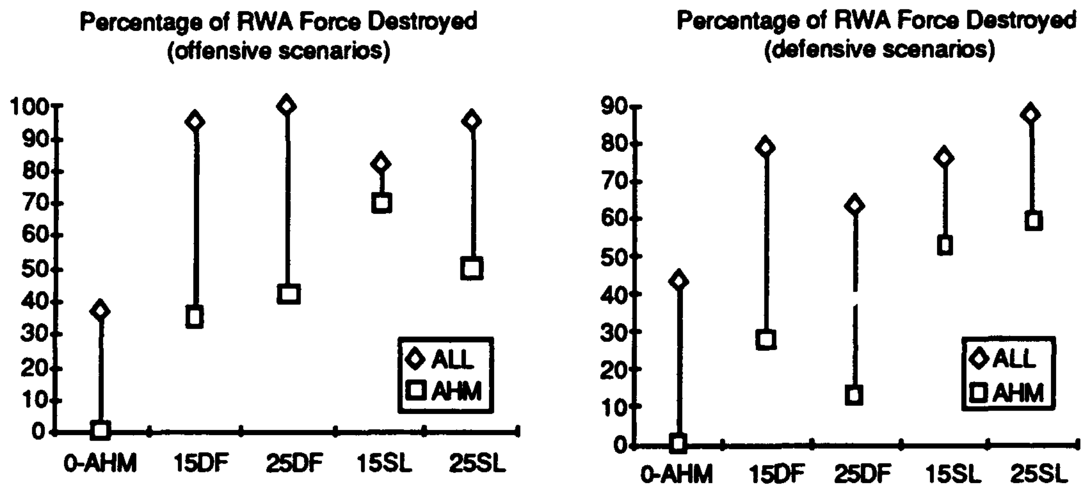

Figure 2. Percentage of RWA Destroyed by Agent

Figure 2 shows that SLAHMs killed more RWA than DFAHM, a total of 43 versus 22 RWA kills over all scenarios. However, total RWA kills by all agents appear to depend on the presence of AHMs but not the type of AHM. This point is reexamined below.

Referring again to Figure 2, AHM kills accounted for 49 percent of the RWA force in the offensive scenarios and 40 percent of the force in the defensive scenarios. Roughly speaking, the difference between AHM kills and kills by other agents is approximately 40 percent, or nearly the same percentage of the RWA force killed when no AHMs were deployed. However, since AHMs tend to kill early in the scenario while helicopters are enroute to their firing positions, for example, fewer targets are available for ADA and direct fire weapons when AHMs are deployed. Nevertheless, the kills for these weapons remain about constant with and without AHMs, suggesting that the presence of AHMs enhances exposure of targets to ADA and direct fire weapons.

A significant amount of player learning took place over the course of the 86 trials. OPFOR learning, primarily, took the form of increased ability to fly and maneuver helicopters through difficult terrain and, to a lesser extent, the futility of certain tactics such as attacking the ADA vehicle. Blue developed a sharpened sense of mine emplacement areas that were likely to be RWA firing positions or routes of ingress. Also, SLAHM maximum engagement range was decreased from 250 to 180 meters. This change increased the probability of hit given a launch from 0.30 to 0.82 and resulted in an increase in the average RWA kills by SLAHM from 1.09 to 1.35 per trial.

The net effect of learning, measured by the difference in armor losses calculated separately for the first and second halves of the trials, is shown in Table 3.

Table 3. Learning Effects on Armor Loss Differences (Mean Blue Minus OPFOR)

Half	DFAHM Offense	SLAHM Offense	DFAHM Defense	SLAHM Defense
1st	0.22	2.0	-5.1	-5.0
2nd	3.89	-0.88	-2.6	-6.7

Armor loss differences increased in the DFAHM trials, but decreased in the SLAHM trials. Although not statistically significant, this pattern is consistent throughout Table 3. The effectiveness of DFAHMs decreased, probably because OPFOR learned to maneuver helicopters more effectively and take advantage of the limited coverage of DFAHMs below the 5-meter altitude. DFAHMs killed 41 percent of deployed RWA (0.94 RWA kills per trial) in the first half of the exercises, but only 19 percent (0.38 kills per trial) in the second half (offensive and defensive combined). The number of DFAHMs deployed was about 20 in both the first and second halves of these exercises; also, the split between the two test regions of the Hunter-Liggett Reservation was nearly the same in both halves.

The effectiveness of SLAHMs increased in the second half of the trials. The average RWA kills by SLAHM increased from 1.18 to 1.35 per trial, even though RWA deployment dropped from 2.4 to 2.0 per trial. Average mine deployment per trial remained relatively constant (18.5 and 19.9). All but one of the first half SLAHM trials took place on one portion of Hunter-Liggett and all but three of the second half took place on a second portion, so the change of venue may have contributed to the apparent learning for SLAHM.

2. Cost-Effectiveness

The unit procurement costs shown in Table 4 were used to calculate simple cost-benefit measures for the effect of AHMs in these trials. For a given set of trials, the cost to Blue is calculated as the value of all Blue armored vehicles lost and all AHMs deployed. (It makes little difference to the results in Table 5 if only launched AHMs are counted as expended.) Dividing this cost by the number of OPFOR armored vehicles destroyed in the given set of trials yields the cost-per-kill results shown in Table 5.

Table 4. Unit Procurement

Hardware Item	Unit Cost ($K)
M1	3600
M2	1100
T72	2400
BMP	733
DFAHM	7
SLAHM	15

Table 5. Blue Cost Per OPFOR Armored Vehicle Killed ($M/Kill)

Measure	Offensive Trials			Defensive Trials		
	0 AHM	DFAHM	SLAHM	0 AHM	DFAHM	SLAHM
Cost Per Kill	7.91	3.29	2.39	3.28	1.34	1.03
Percent Reduction	-	58.3 percent	69.7 percent	-	59.0 percent	68.5 percent

Because AHM costs are always less than 3 percent of total Blue costs and sometimes less than 1 percent, the results in Table 5 are very insensitive to the unit cost of AHMs. An order of magnitude increase in AHM unit costs changes the percent reduction in cost per kill by only a few percent.

Another cost-benefit measure is return on investment, defined for these trials as the dollar value of Blue vehicles saved plus the dollar value of additional OPFOR armored vehicles killed divided by the cost of AHMs deployed. Table 6 shows some results of this calculation. RWA killed have been ignored in cost calculations to allow (conservatively) for the possibility that all RWA kills were only mission abort.

Table 6. Return on Investment

Trials	DFAHM	SLAHM
Offensive	115	71
Defensive	79	58

D. CAUTIONS AND CONCLUSIONS

This paper reports the results of an exploratory SIMNET investigation of the combat potential of AHMs and of some of the operational factors that influence AHM effectiveness. The 86 trials that were conducted do not constitute a controlled experiment. Conditions of the later trials differed from those of the earlier trials. No attempt was made to control learning over the course of the trials, which had a major effect on the results (and may offer valuable insights). As can be seen in Table 1, even with 86 trials the number of trials per cell is rather small and there is considerable variability within each cell.

1. General Conclusion

In spite of their limitations, these trials provide strong evidence that in circumstances that favor their use, AHMs can play an important role, even making the difference between defeat and victory. The specific condition used in these trials involved a highly effective air defense system that restricted RWA operations to low altitudes in limited areas, highly effective RWA that could usually result in Blue defeat, and AHMs that could usually deprive OPFOR RWA of the maneuver space required to attack Blue armor. Under these circumstances, AHMs were highly effective and yield a return on investment ratio that varies from 50 to over 100 (ignoring the possible dollar value of RWA killed and of AHMs that are recovered).

Although the combat value of AHMs in particular situations is clear, the question of how frequently such situations will arise will have to be answered judgmentally. These situations need not have such a clear-cut structure as the trials in this study, but the following general characteristics seem essential for high AHM payoff in short duration scenarios:

- Enemy RWA must represent a major threat. In these trials, attack helicopters threatened Blue armor. In other scenarios, dismounted Blue personnel might be threatened or the threat might be an airborne assault.
- Enemy RWA, or the operation of which they are a part, must pay a big penalty if RWA do not operate within a three-dimensional envelope that prevents overflight or lateral circumvention of AHMs during critical portions of the

RWA mission. In these trials the RWA envelope was restricted by a highly effective air defense system and by the assumption that the engagements were part of a larger operation so that RWA, for example, could not attack from the rear. In other scenarios, less effective but more numerous air defense or the OPFOR's need to conceal the mission could impose the necessary restriction. In some scenarios, the OPFOR mission itself in combination with the terrain may limit the allowable envelope sufficiently, e.g., to a small number of landing zones.

- If AHMs are to have a high payoff, then enemy RWA must remain a significant threat in spite of the limitations on their flight paths and AHMs must be the most effective (or practical or only) means of countering this threat. In these trials, RWA could find ingress paths that were masked from the air defense and attack positions that outranged antihelicopter weapons on the Blue armor. In other scenarios, economy of force considerations may prevent air defense coverage of likely RWA attack positions.

The third condition has certain implications. The AHMs must be able to cover a significant portion of the restricted RWA operational envelope so that there is a reasonably good probability that RWA will be engaged by AHMs. There should not be any part of the restricted RWA envelope that the enemy can predict will be safe from AHMs. The probability of kill or mission abort given an RWA enters an AHM field must be reasonably high.

In these trials, a small number of high performance AHMs were able to cover the masked RWA ingress paths and the areas from which RWA could attack effectively. A larger number of lower performance AHMs would not seem excessive and would work as well. More critically, it was assumed that AHMs could be emplaced forward of the Blue forces. The extent to which AHMs can be emplaced forward of Blue forces may be a major determinant of whether or not they can deprive OPFOR RWA of the air space they require.

If these three conditions are met, then AHMs will have a high payoff, for example, in loss exchange ratio, in preventing certain enemy operations, or in economy of forces. In this study, these conditions could be satisfied for both pieces of terrain whether Blue had the offensive or defensive role.

2. Effectiveness of DFAHM and SLAHM

Although these trials are too limited to allow general quantitative comparisons of DFAHM and SLAHM, some observations can be made about each of these two mine concepts.

a. DFAHM

It is obvious that the DFAHM concept is sensitive to RWA flight altitude. The engagement area covered by an individual DFAHM against RWAs flying at altitude h is proportional to h^2. When h is small, so is this area, and the probability that the DFAHM will have an opportunity to engage is much smaller than at higher altitudes. Whether modest design changes could increase low altitude coverage is unknown.

The extent to which this characteristic of DFAHMs will limit their effectiveness depends on such things as the terrain, which may make very low altitude flight difficult or impossible, and the penalties that such flight entails, e.g., lower speed. Even so, it seems likely that DFAHMs will be more effective when used in areas where helicopters must be at least several tens of meters above the ground to perform their mission. In these trials, DFAHMs were effective in those areas where RWA popped up to attack Blue armor.

The pattern of results for DFAHMs in these trials is suggestive. Overall, force effectiveness with the DFAHM was similar to, but somewhat lower than, force effectiveness with the SLAHM. Given the difference in coverage of the two types of mines and the fact that they were used in the same numbers, this result seems a little unexpected. However, as shown earlier in Table 3, if only the second half of the trials is examined, then force effectiveness with DFAHMs is quite a bit lower than with SLAHMs. The OPFOR player's learning and skill in maneuvering RWA were far more significant for the DFAHM than for the SLAHM. This phenomenon might occur in the field.

Another interesting result is that, on the one hand, when mines were present, the number of helicopters killed was on average much greater than when no AHMs were present, and this difference was approximately independent of whether DFAHMs or SLAHMs were employed. On the other hand, DFAHMs killed fewer RWA than SLAHMs. It appears that OPFOR's knowledge that AHMs are present and his attempt to avoid them distracts the OPFOR player or otherwise causes him to expose the RWA to Blue weapons. This phenomenon also may occur in the field.

b. SLAHM

Force effectiveness with SLAHMs improved in the second half of the trials, in part because maximum engagement range was reduced from 250 to 180 meters. This change reduced the engagement area by about 50 percent, but in these trials that penalty was less significant than the dramatic increase in hit probability. This may not be true in other scenarios or may not be true at all times in the same scenario. For example, as a minefield is depleted, it may be desirable to close gaps by expanding the coverage of the remaining mines.

The choice of maximum engagement range involves a major scenario-dependent tradeoff between coverage and hit probability. At a minimum, this parameter should be "settable" before the SLAHMs are emplaced. Even better, would be a command and control capability to change the setting after the SLAHMs are emplaced.

E. ORGANIZATION OF REPORT

Chapter II describes the structure of the trials in terms of the simulation of AHMs, the scenarios, and the test procedures that were followed. Chapter III presents the results of the 86 trials that were conducted. These results include measures of effectiveness, an examination of the effect of spacing between mines, simple cost-benefit analyses, and a discussion of the effects of player-learning during the course of the trials.

II. REPRESENTATION OF AHMs, SCENARIO DEVELOPMENT, AND TEST PROCEDURES

This chapter provides descriptions of the SMS representation of the two types of AHMs, the scenarios that were used in the test, and the test procedures that were followed.

A. SMS

1. Development

IDA developed the initial specifications for a smart-mine simulator. The intent was to produce a set of specifications or a functional description that could be implemented quickly by a software developer, while still representing broad distinctions between two actual smart-mine concepts. Elementary tracking or sensing procedures, target selection, and launch sequences were represented. Complex aspects of these three steps in actual designs, e.g., Kalman filters applied to the tracking process, were not modeled.

The specifications called for a stand-alone simulation of direct-fire AHMs, sublet-launched AHMs, and sublet-launched antiarmor mines. Each type of mine has the ability to detect and identify targets in its immediate vicinity, select an appropriate target, determine a firing solution, and intercept the target. The effects of degraded sensor and munition reliability are modeled by user inputs.

In order to communicate and interact with SIMNET vehicles, the underlying software receives and transmits SIMNET protocol data units (PDUs). Appearance PDUs are processed to determine the location and state vectors of nearby vehicles. Fire and impact PDUs are transmitted for use by target vehicles in calculating the effect of mine munitions.

Loral Aerospace developed the simulation software at their Fort Knox facility and designated it the (initial) Smart-Mine Simulator, or SMS. It is written in the C programming language and is currently implemented at IDA on a MASSCOMP host under a UNIX operating environment. Input data sets consist of an ASCII file of mine types and positions, and an ASCII file of certain performance parameters. The latter consist of sensor cone size and shape, EFP hit probabilities given a launch for each type of mine,

and, in the case of sublet mines, launch criteria based on the anticipated closest point of approach (CPA) of the target.[1]

2. Software and Algorithm Description

a. DFAHMs with Sensors

DFAHMs are dormant until RWA fly within a user-specified range, at which point the DFAHMs become active. Upon activation, DFAHMs sample potential targets five times per second to determine if they are within the mine's effectiveness region. The sensor cone is a 90_ right regular cone with 100-meter altitude and vertex on the ground at the mine's position. As shown in Figure 3, the effectiveness region is defined by a specified angular tolerance (±20_ in these exercises) of the boundary of the sensor cone. If a target is detected in this region, a random draw determines if an impact packet is issued over the SIMNET network to inform the target RWA that it has been struck by an antihelicopter munition. If an impact packet is sent, a second random draw determines if the RWA is destroyed by the impact. Each mine is capable of "firing," only once.

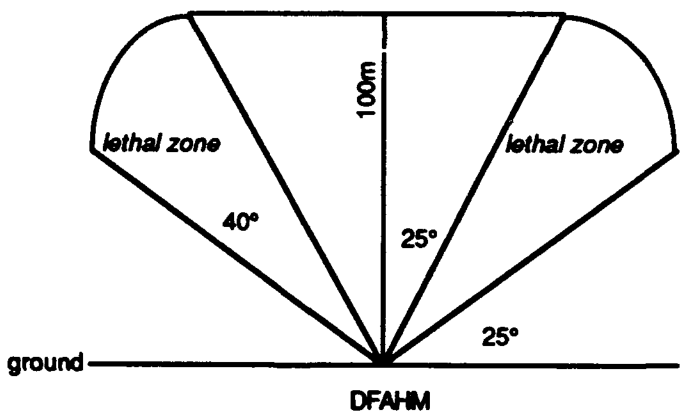

Figure 3. DFAHM Operational Cross Section

The angular tolerance was chosen to be ±20_ to compensate for the 5 Hz sampling rate. In most cases, RWA flew no higher than 5 meters, and often as low as 2 meters above the terrain when within range of ADA. The thickness of the cone's "skin" (with a 20_ tolerance) at 2 meters altitude is about 3.36 meters. Standard SAF parameter settings

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[1] SMS-Version 1.0 written in C++ was completed in October 1993. A user's guide is available.

permitted RWA to accelerate to nearly 100 knots when moving in a straight line over modest distances, even at altitudes as low as 2 meters. This speed translates to about 52 meters per second, or 10.4 meters per 0.2 seconds. Thus, to prevent RWA from passing through the sensor cone undetected, except occasionally when flying extremely low, the tolerance had to be set appropriately. (A simple geometric analysis indicates that an RWA flying at 100 knots, 2 meters directly above the AHM, has a 35 percent chance of passing through the sensor cone undetected; assuming a uniform distribution of offset from the center of the cone, the probability of this RWA passing through undetected is on the order of 15 percent.)

For these tests, the probability of hit given an EFP firing (i.e., of issuing an impact packet) was set to unity, as was the probability of kill given an impact. (Because of overkills, actual trial results indicate a probability of kill (Pk) ratio of kills per launch of about 0.8; see Chapter III.) The interpretation of these parameter choices is discussed in Chapter III.

b. SLAHMs

The SLAHM operates differently from the direct-fire version; it does not fire EFPs at a target from its base point on the ground (see Figure 4). Instead, it launches a ballistic projectile in the direction of an incoming RWA if the target's trajectory is expected to pass within a specified distance of the AHM's base position. Two launch angles are possible depending on the offset distance of the trajectory from the AHM: 45_ for offsets beyond 10 meters and 80_ within 10 meters. Launch speed is 50 meters per second, resulting in ground ranges of approximately 250 meters and 86 meters, respectively (corresponding flight times are about 7 and 10 seconds).

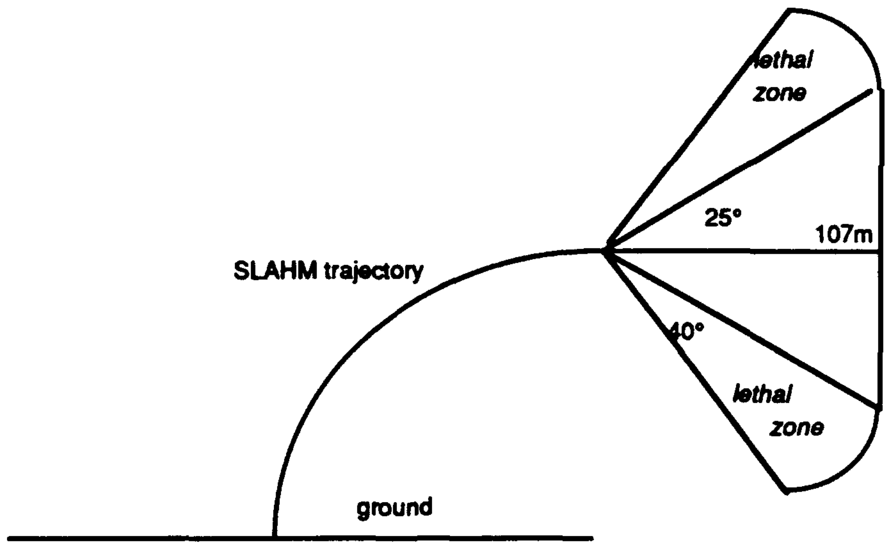

Figure 4. SLAHM Operational Cross Section

The projectile carries a multiple EFP warhead and a sensor that rotates about a horizontal axis, forming a conical effectiveness region that functions in a manner similar to the vertical cone of the DFAHM. The slant height of the cone and angular tolerance are input parameters, set to 152 meters and ±20_, respectively for these exercises.

Potential targets are sampled 10 times per second, twice as frequently as the DFAHM. (The higher sampling rate of the SLAHM is intended to compensate for the potentially higher relative velocities encountered during SLAHM intercepts as compared with the stationary DFAHMs.) Depending on a random draw, an impact packet is issued for an RWA detected by the sublet within the effectiveness region. As in the DFAHM case, the probabilities of hit (impact) given a detection and kill given a hit were set at unity. Again, because of overkills, the kills per launch was about 0.8. Each SLAHM carries only one munition.

3. Implementation and Use

The smart-mine simulation was used in these exercises by first preparing a set of input files specifying mine type (DF or SL) and mine locations. Mine locations were specified individually although the software permits the emplacement of entire minefields at one time. Once emplaced and activated, the SMS operated autonomously.

Reports of mine activity, including detections, launches, impacts, and, on occasion, time-outs, are obtainable from the SMS diagnostic software. These reports were of

substantial value to the Blue operator in deciding on mine emplacement during subsequent trials.

B. SCENARIO DEVELOPMENT

1. Force Levels and Terrain

These exercises were conducted using the SIMNET Hunter-Liggett terrain database. The scenarios Offense_1 and Defense_1 are based on the Movement to Contact and Defend in Sector phases of the April 1988 SIMNET/FAADS exercise and are conducted in Hunter-Liggett's Stony and Nacimiento Valleys. Borrowing the rationale used in the earlier exercise, the activity taking place in these valleys is assumed to be part of a 10th U.S. Corps engagement extending from the west coast to the Salinas Valley in the east.[2] Scenarios Offense_2 and Defense_2 are conducted with the same forces, but further to the southeast in the region of Hunter-Liggett bordering the Sam Jones Gunnery range.

Force levels were reduced from those of the FAADS exercise to make the maneuver functions manageable for the two game players. In particular, in all scenarios, Blue operated only one ADA vehicle (as opposed to an ADA platoon in the FAADS exercises) and OPFOR flew either two or three attack helicopters. In the offensive scenario, Blue armor forces were two M1 platoons and two M2 or infantry fighting vehicle (IFV) platoons opposed by one T72 platoon and one BMP platoon. In the defensive scenario, the Blue armor force levels were one M1, one M2 platoon opposing two T72 platoons and two BMP platoons. (All Blue platoons and OPFOR tank platoons contain four vehicles, but the BMP platoons only contain three vehicles). OPFOR operated flights of 3 RWA in 13 offensive scenario trials and in 2 defensive trials. In all other cases, flights of two RWA were deployed. Tables 7 and 8 summarize the force levels of each side.

Table 7. Blue Force Levels

Scenario[a]	M1 Platoons	M2 Platoons	ADA	Vehicles
Offense	2	2	1	17
Defense	1	1	1	9

[a] Offense and defense refer to the disposition of the Blue Forces.

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2 Bolt, B.E., Johnson, C., Letter Report for Forward Area Air Defense System (FAADS), Line-of-Sight-Forward-Heavy (LOS-F-H), Simulator Network (SIMNET) I Exercise, November, 1989.

Table 8. OPFOR Force Levels

Scenario[a]	T72 Platoons	BMP Platoons	RWA	Vehicles
Offense	1	1	2 or 3	9 or 10
Defense	2	2	2 or 3	16 or 17

[a] Offense and defense refer to the disposition of the Blue Forces.

Both offensive scenarios were constructed so that, in the mean, OPFOR could not defeat Blue armor without the assistance of attack helicopters. On the other hand, Blue armor could not defeat OPFOR armor when RWA operated freely within envelopes masked from ADA coverage. Defensive scenarios were developed by interchanging the position of Blue and OPFOR armor units. This force balance became the rationale for introducing AHMs to the battlefield.

2. Application of AHMs

In all scenarios, ADA positions were selected to minimize ADA vulnerability to the RWA and to give the ADA an ample view of the RWA operating region. In Offense_1, the Blue offensive in the Nacimiento Valley, the Blue ADA vehicle was placed on a hill crest near FQ510833 (see Figure 5). With OPFOR defending near FQ550800, ADA was generally out of range of enemy armor and helicopter forces. (RWA occasionally attempted to attack the ADA by carefully making their way along the ridge line separating Stony Valley to the north from Nacimiento Valley to the south. These occurrences were rare in the 27 trials in Offense_1.) On the other hand, this position afforded Blue ADA an excellent view of both valleys. Hence, OPFOR helicopter operations were, to a great extent, limited to those regions that were either beyond ADA range or to areas that were obscured from ADA line-of-sight.

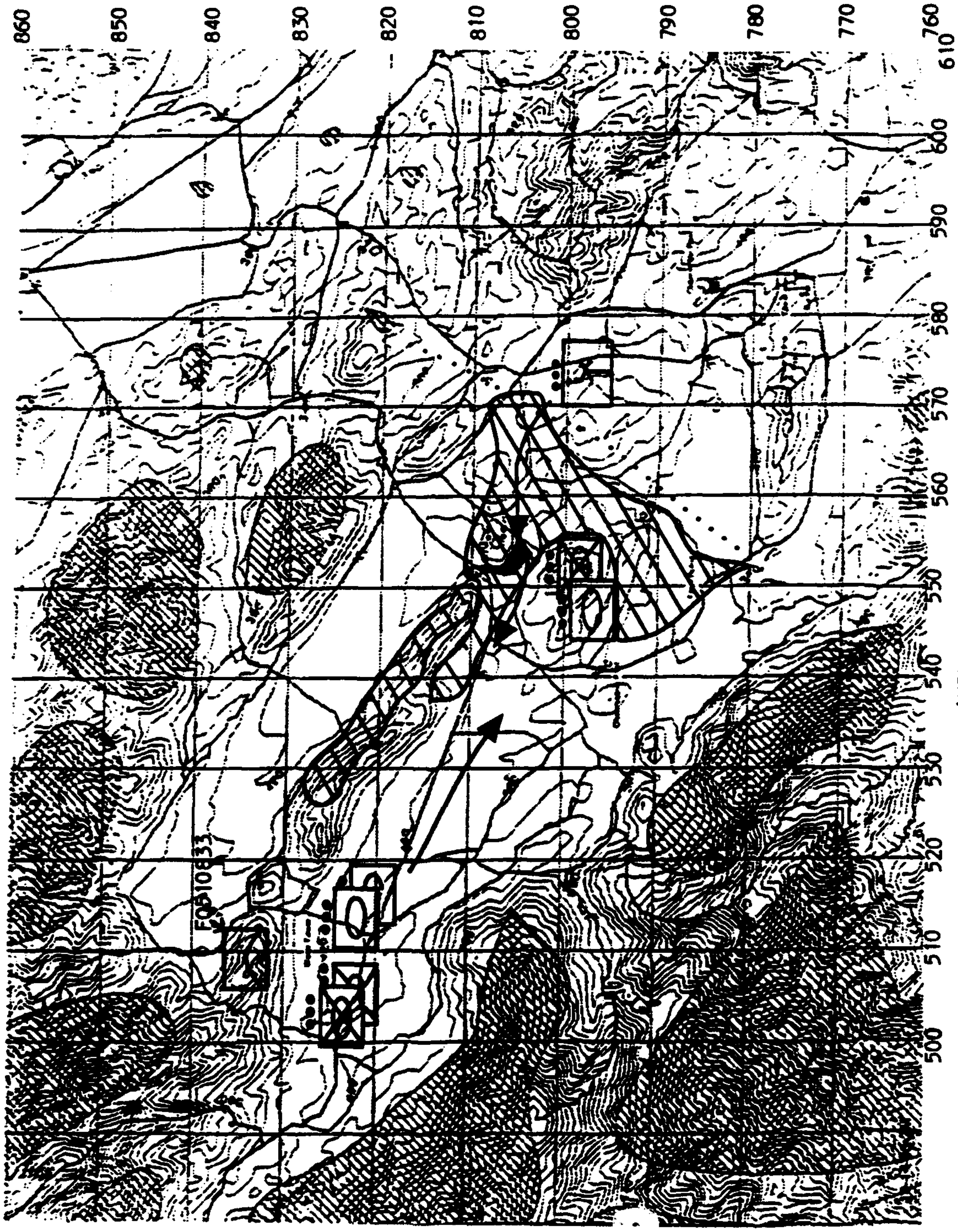
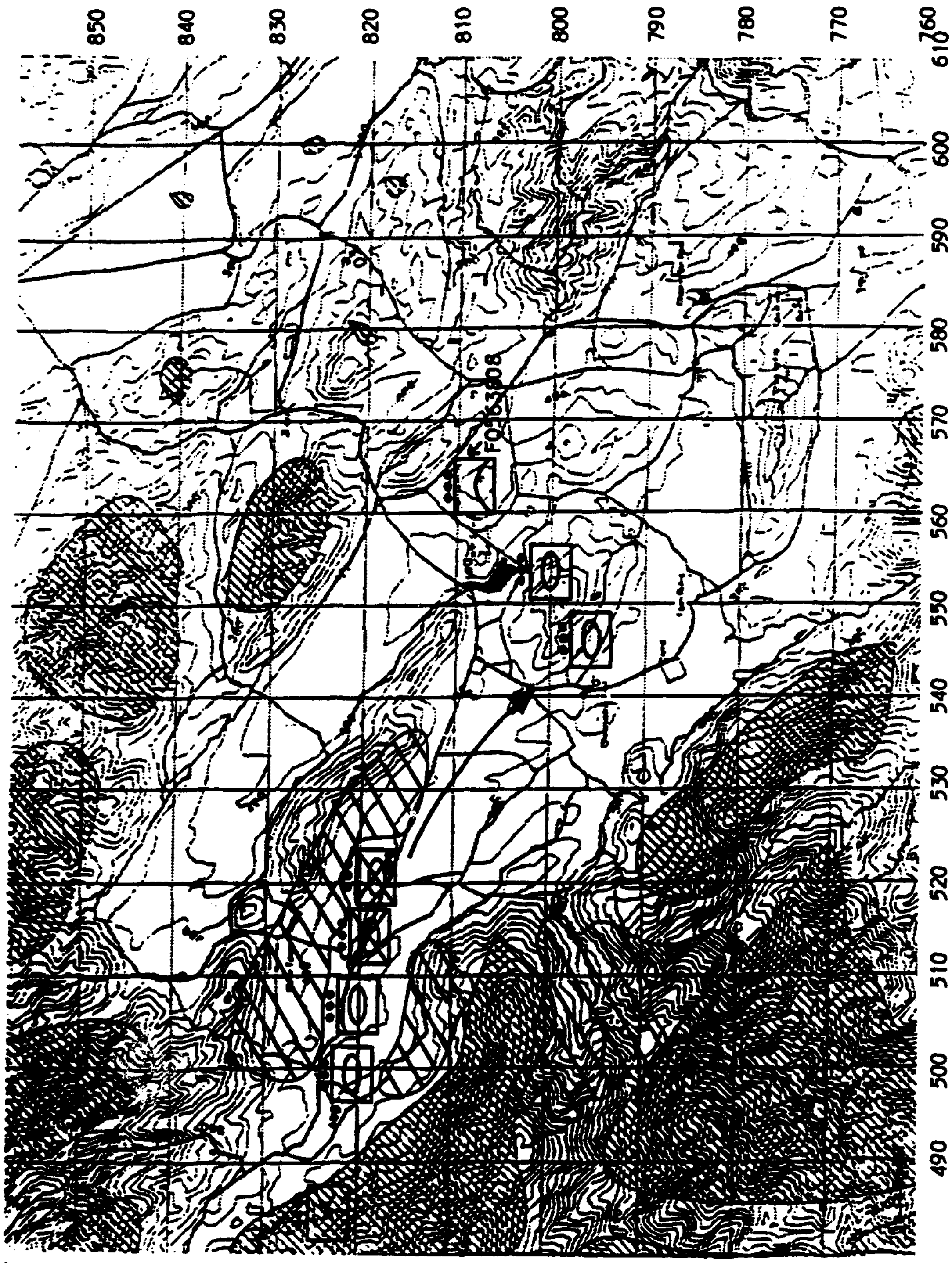


Figure 5. Offense_1

Regions beyond ADA range were of limited value as a defensive position for RWA because Blue armor would be able to engage OPFOR armor well before coming into RWA munition range, approximately 3.5 kilometers (km) in these exercises. Thus, the only viable option for the RWA was to fly within the "pockets" obscured from the ADA and attempt to engage Blue armor at ranges that exceeded the range of Blue armor munitions. These ranges were 1,571 meters for M1 tank guns and 2,751 meters for M2 tube-launched, optically tracked, wire-guided (TOW) missiles when Blue was in an offensive posture. By making use of the various terrain analysis features available in SAF/4.3.3, one can determine that the projection onto the terrain of the effective operating region for the RWA was largely bounded by the 2 km^2 rectangle determined by vertices FQ550810 and FQ570800. This determined the most effective area for mine emplacement.

In Defense_1, Blue Defense in Nacimiento Valley (see Figure 6), the ADA position was selected with the same issues in mind. In this scenario, the ADA vehicle was placed on a hilltop near FQ563808. From this vantage point, most of Stony Valley was visible and therefore not a viable operating region for RWA. Similarly, the southern portion of Nacimiento Valley was in full view of the ADA. The only area from which the RWA could attack the Blue armor, positioned near FQ550800, was the portion of Nacimiento Valley southwest of the ridge separating it from Stony Valley and northeast of Nacimiento Road. Again, only about 2 km^2 of this area was within RWA munition range of the Blue armor.

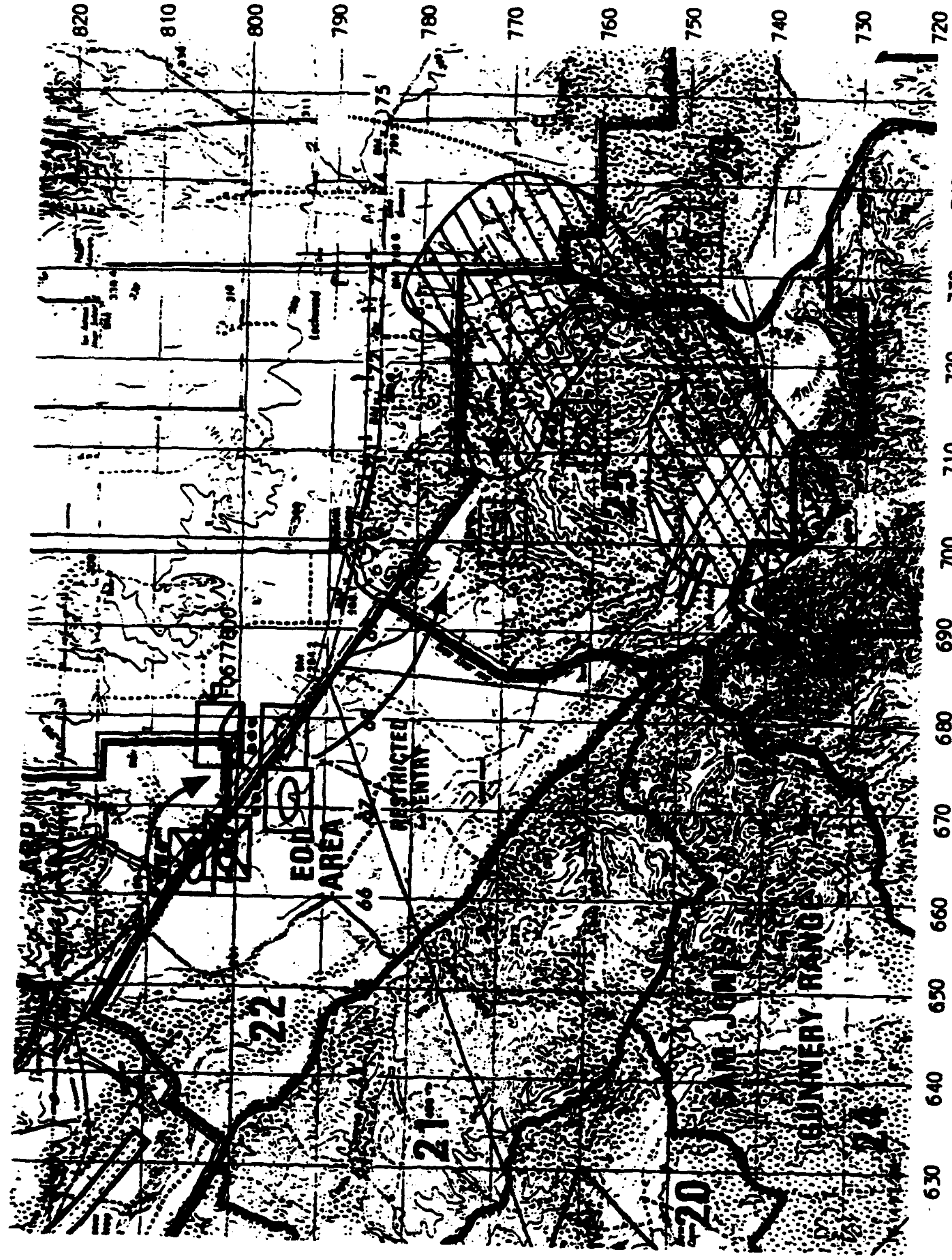
In Offense_2, Blue offense in the Sam Jones Gunnery Range (see Figure 7), the ADA vehicle moved during the course of the exercise from a point behind the initial position of the attacking Blue armor to a hilltop near FQ677800. Once on top of this hill, ADA restricted helicopter movement to the hills behind the OPFOR armor positions near FQ710760 and to the neighborhood of Earts Reservoir. The former offered few long-range engagement opportunities because the hills obscured the Blue armor from view. On the other hand, the reservoir region formed a depression in the terrain from which RWA could lie in wait to ambush oncoming Blue forces. Terrain analysis indicates that the RWA could operate safely and effectively within a corridor approximately 3 km long and 1 km wide.



(UTM Patch FQ)

Figure 6. Defense_1

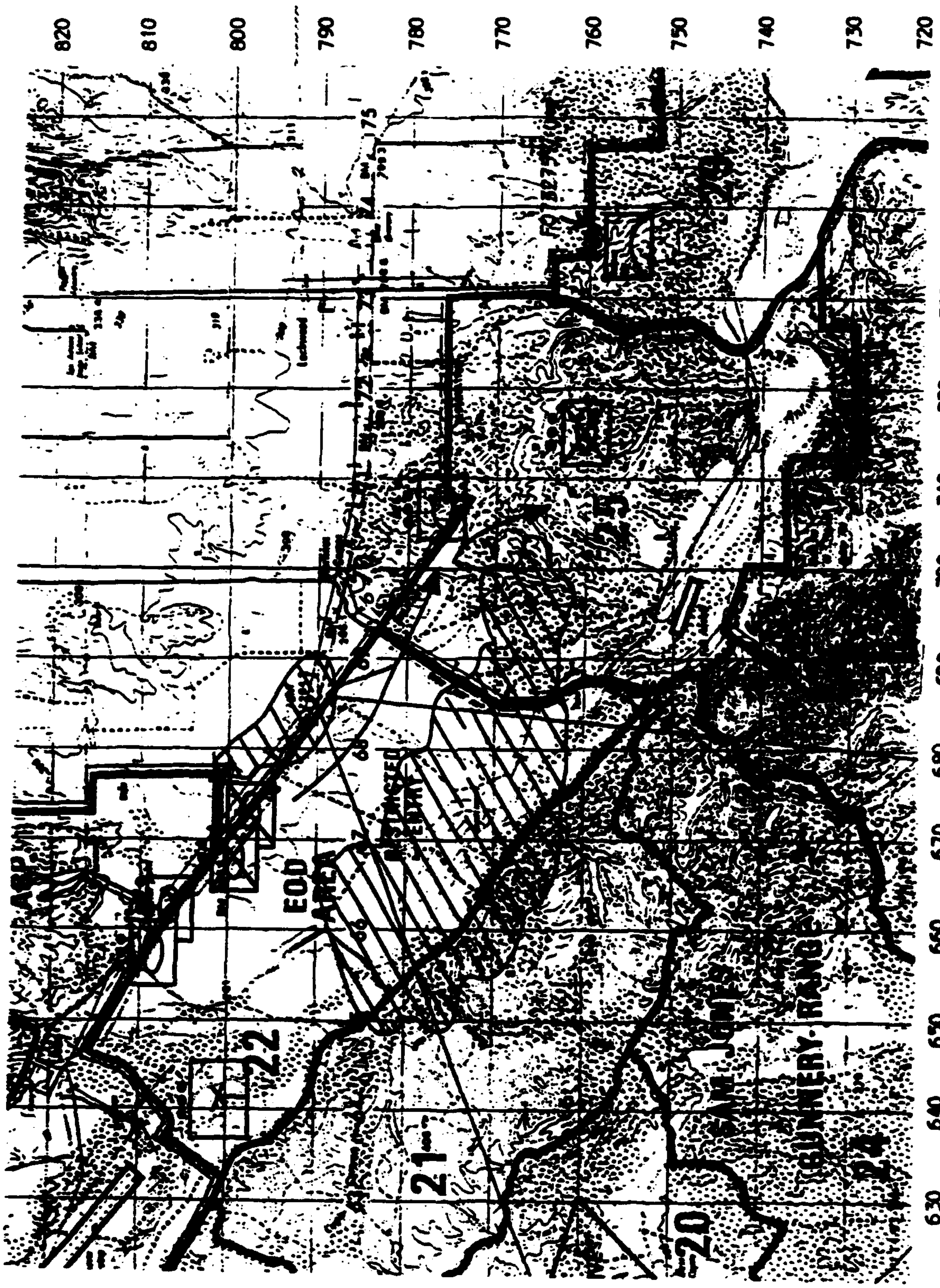
Figure 7. Offense_2



Finally, in Defense_2, Blue defense in the Sam Jones Gunnery Range (see Figure 8), ADA was placed on Jackson Hill, near FQ732757. This was the second highest hill in the immediate area of the Blue defensive position near FQ710760. The highest position was not selected because trial runs indicated that RWA would not survive long enough to contribute to the engagement. They had no sanctuary positions in which to hide from the ADA. With the selected ADA location, RWA could operate in two distinct regions. The first was a conical shaped corridor stretching west-northwest of the Blue mechanized infantry position. The portion within striking range of Blue was on the order of 4 km^2. The second was a narrow area about a kilometer long and half a kilometer wide immediately south of a prominent hill near FQ677800 (the ADA position in Offense_2). The first region was masked from ADA by the hills on which Blue IFVs were positioned, and the second area was masked by the highest hill mentioned earlier.

Generally, if an RWA successfully entered a sanctuary region and managed to remain within 3.5 kms of the IFVs without falling within range of their munitions, the RWA would destroy the IFVs. This, in turn, often ensured a victory for OPFOR because Blue would be deprived of its long-range antiarmor weapons.

Figure 8. Defense_2



C. TEST PROCEDURES

1. Free Play Exercises

a. Blue Responsibilities

Mines were individually emplaced by the Blue player before the start of each game. The OPFOR player had no direct knowledge of the location of the mines but knew as well as the Blue player which areas were not well covered by ADA and, thus, were likely candidates for AHM emplacement. However, the number of mines used was relatively small, and the options for covering routes of ingress or probable firing positions were limited. Hence, there was a fair amount of uncertainty about exactly where AHMs were emplaced. This uncertainty was a critical factor in the play of the game.

Two people played each exercise: one controlling Blue and one controlling OPFOR. The Blue player had access to the SMS host and emplaced AHMs at points of his choosing by editing input data files accessed by the SMS software. The other function of the Blue player was to maneuver Blue armor units. In many cases, the routes used by Blue vehicles were selected before each exercise and were automatically followed once the trial began. In such cases, Blue could intervene in the course of a trial but, otherwise, had no responsibilities beyond emplacing and activating minefields.

b. OPFOR Responsibilities

The OPFOR player was responsible for maneuvering OPFOR armor and flying the RWA. The latter required exacting attention and manual dexterity. As the "safe areas" for the helicopters were limited and the ADA and other anti-helicopter munitions were highly effective, it was important for the OPFOR player to exercise precise control over the RWA at all times. SAF helicopters are "underdamped systems" that will move well beyond their designated destinations unless they are moved very carefully. Generally, this means they can be directed to move only a few hundred meters at a time when in or near areas of danger. RWA movement, like that of all SAF units, is controlled by "clicking" an electronic mouse over a point within a terrain map or on a menu item contained in a "window." Because equipment was limited, both players had to share the same mouse and workstation to maneuver forces, unless the routes of their respective forces were

preplanned. Because all units were displayed on one terrain map, each player knew his opponent's positions, with the exception of minefield locations.[3]

2. Test Matrix

Players conducted 46 trials of 2 offensive scenarios and 40 trials of 2 defensive scenarios. Each trial was classified by scenario, type of AHM used, and number of AHMs deployed. In the next chapter, results are presented for the two offensive scenarios combined and the two defensive scenarios combined for the different numbers and types of AHMs. Three levels of AHMs were used by the Blue player: 0, approximately 15, and approximately 25. (Actual numbers of mines emplaced varied slightly from these values: 13 to 15 in the mid-level cases and 22 to 25 in the high-level cases.) The number of trials in each category is presented below in Table 9.

Table 9. Distribution of AHM Tests

	Number and Type of AHM				
Scenario	**0 AHM**	**15 DF**	**25 DF**	**15 SL**	**25 SL**
Offense	12	9	9	7	9
Defense	7	7	8	10	8

3. Data Collection

Data were collected during and after each game. The number of armor kills was simply counted from the workstation screen when each engagement came to a conclusion, generally when one side had been annihilated. The number of AHM launches, hits, and kills were recorded by directing all output from the SMS software package to a data file, which could be read and analyzed "off line." Kills by RWA are difficult to observe or distinguish from kills by OPFOR armor while the games are in progress. These were tabulated after the games were concluded from the Table-Logger, a software package that captures and stores data packets associated with any given exercise.

3 Additional Silicon Graphics workstations have since become available. These would permit separate Blue and OPFOR workstations in future trials.

III. RESULTS

A. MEASURES OF EFFECTIVENESS

1. Exchange Ratios

a. Offensive Scenarios

This section presents combined results from the two offensive scenarios. Figure 9 summarizes the average armor losses for the Blue and OPFOR forces, versus the number and type of AHMs, across all 46 exercises in which Blue was on offense. It is clear that average Blue losses decrease and average OPFOR losses increase, relative to the base case, whenever AHMs are present.

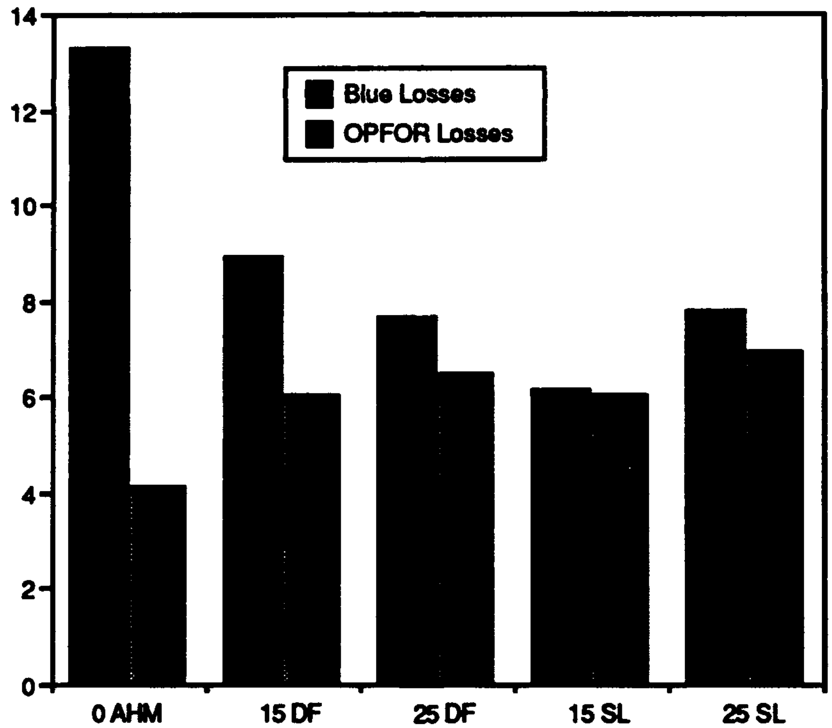


Figure 9. Average Armor Losses--Offensive Scenarios

A different summary of the same trials is presented in Figure 10. The top of each vertical line represents the maximum of Blue armor losses minus OPFOR armor losses

over the trial category. The bottom of each line represents the minimum of that difference. The arrowhead between the two extremes represents the mean of the differences over the entire category.

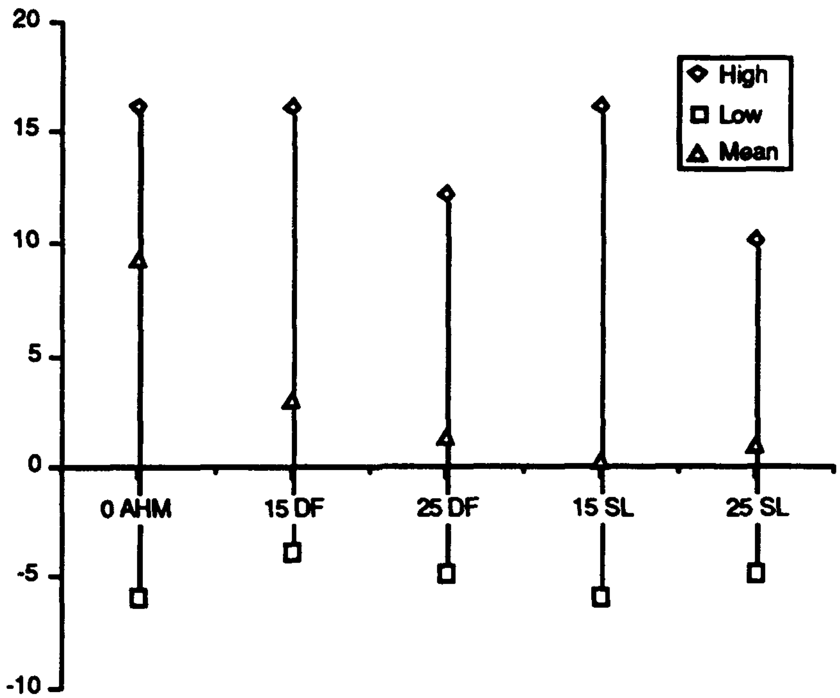


Figure 10. Difference in Armor Losses (Blue Minus OPFOR)

The t-statistic applied to the difference between mean armor losses in the trials with no AHMs (9.17) and the trials in which AHMs were present (1.35) yields a value equal to 3.52, which is significant at the 0.003 level. Although in these trials, AHMs have a very strong effect on outcome measured in terms of the differences in armor losses, the appropriate F-statistic applied to the four trial categories in which AHMs are present is about 0.30, indicating no significant difference among these categories.

Military analyses often focus on exchange ratios, as opposed to loss differences. These ratios (OPFOR armor losses divided by Blue armor losses) are displayed in Figure 11 for the offensive scenarios. Relative to the base case, the exchange ratio increases two to three times in each of the AHM trial categories. The exchange ratio is higher when averaged over all the SLAHM trials than when averaged over all the DFAHM trials (0.92 versus 0.75). .

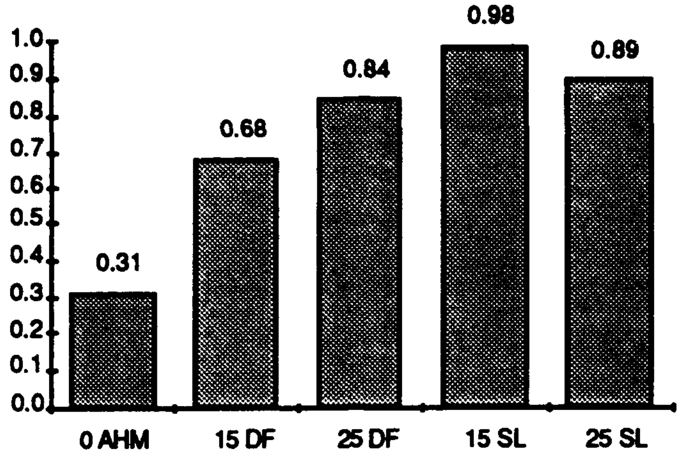


Figure 11. Exchange Ratio (OPFOR Losses ÷ Blue Losses)--Offensive Scenarios

The standard errors associated with exchange ratios varied from a low value of 0.08 for the 0 AHM category to a high of 0.44 for the 15 SLAHM category. In all other cases, the standard error was less than 0.20. Relative error, the standard error expressed as a percentage of the exchange ratio, was largest (45 percent) in the 15 SLAHM category. In all other cases, it varied between 20 percent and 30 percent. Table 10 contains standard and relative errors for all trial categories.

Table 10. Exchange Ratio Standard and Relative Errors

0 AHM	15 DF	25 DF	15 SL	25 SL
0.08	0.2	0.17	0.44	0.15
26 percent	29 percent	20 percent	45 percent	17 percent

b. AHM Defensive Scenarios

The following graphs depict the armor losses for Blue and OPFOR in the defensive scenarios. Figure 12 shows the average losses for each side, while Figure 13 displays the maximum, minimum, and mean of the differences between the Blue and OPFOR losses.

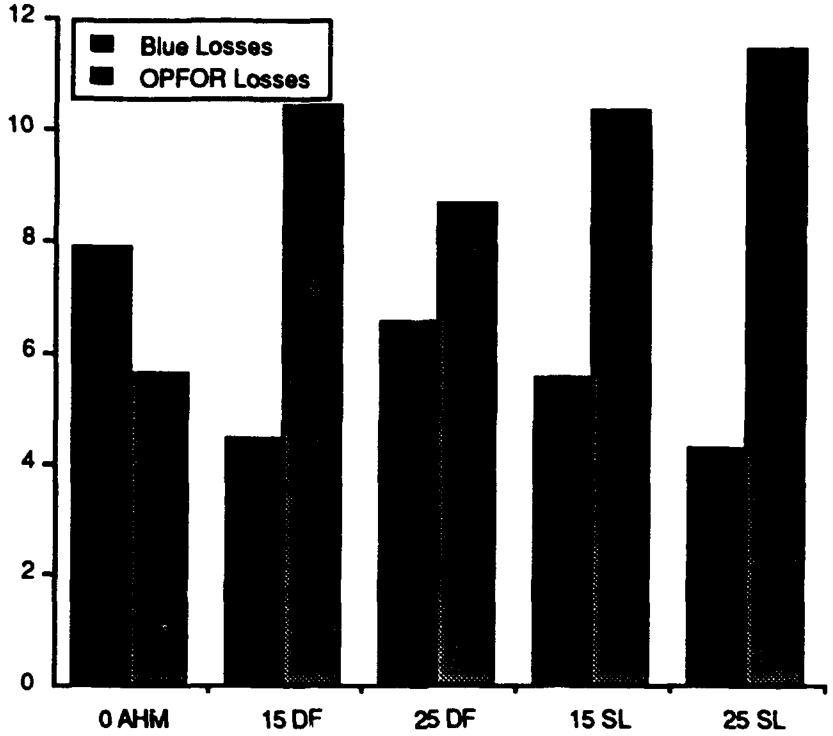


Figure 12. Average Armor Losses--Defensive Scenarios

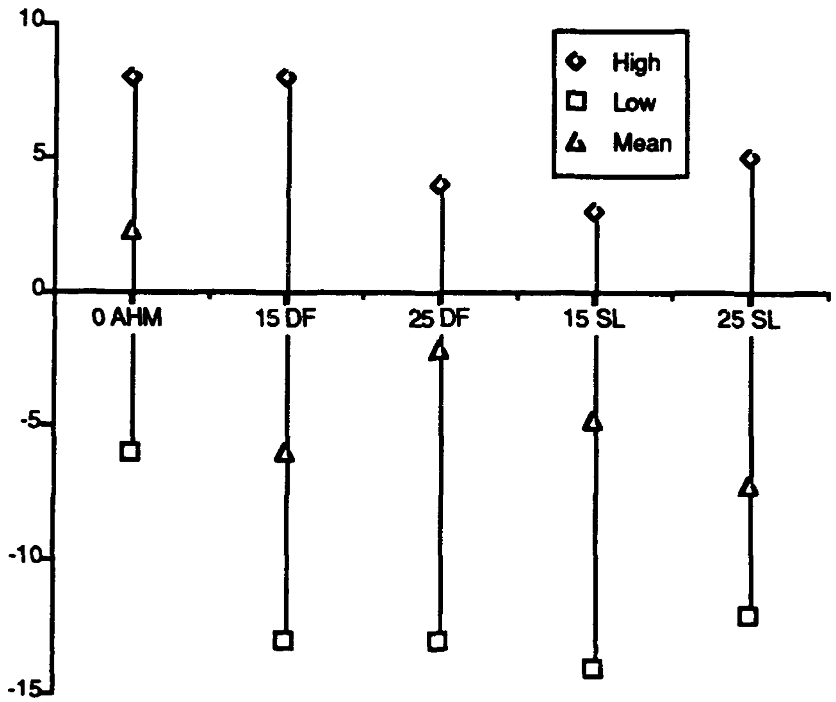


Figure 13. Difference in Armor Losses (Blue minus OPFOR)

Again, the effect of AHMs on Blue and OPFOR losses is dramatic. The only cases in which the average Blue loss is greater than those of OPFOR are the 0 AHM cases. The t-statistic applied to the difference between the mean losses in the 0 AHM trials (2.3) and those trials with AHMs (-5.0) equals 3.15, indicating a significant difference at the 0.01 level. As in the case of the offensive scenarios, however, no significant difference was found among the cases in which AHMs were present (the appropriate F-statistic equals 0.765).

The exchange ratios for the defensive scenarios are given in Figure 14. Once again, the exchange ratios improve by factors that range from slightly less than 2.0 to 3.8. The overall SLAHM average exchange ratio is 2.18 compared to 1.71 for DFAHM.

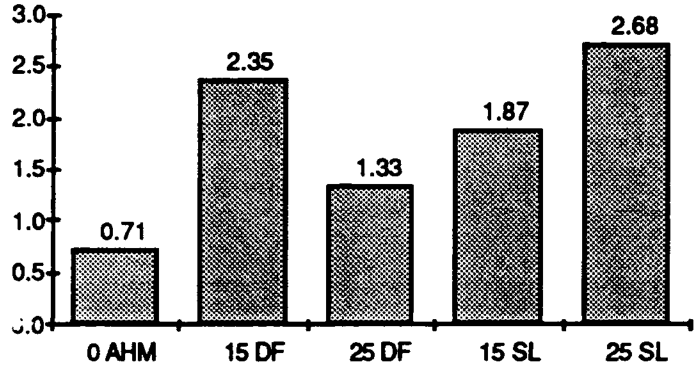


Figure 14. Exchange Ratio--Defensive Scenarios (OPFOR Losses ÷ Blue Losses)

The standard errors associated with these exchange ratios varied from a low of 0.25 for 0 AHMs to a high of 1.0 for the 15 DFAHM category. The high value of the latter is difficult to explain: in two of the seven trials in this category, the exchange was equal to 14; three other trials resulted in exchange ratios less than 1.30; the two remaining trials gave 3.25 and 7.0, respectively. Standard and relative errors are given in Table 11, below.

Table 11. Exchange Ratio Standard and Relative Errors

0 AHM	15 DF	25 DF	15 SL	25 SL
0.25	1.0	0.37	0.54	0.93
36 percent	42 percent	28 percent	29 percent	35 percent

2. Kills by and of Helicopters

a. Offensive Scenarios

Helicopters were major OPFOR weapons in these exercises. When OPFOR was able to bring them to bear against Blue, OPFOR was usually successful. This was true in both the offensive and defensive scenarios. Figure 15 shows kills of Blue armor by RWA for the offensive scenarios. These data were taken from Table-Logger files and, because the Logger was not available during all tests, are based on 10 fewer cases (i.e., on 36 tests).

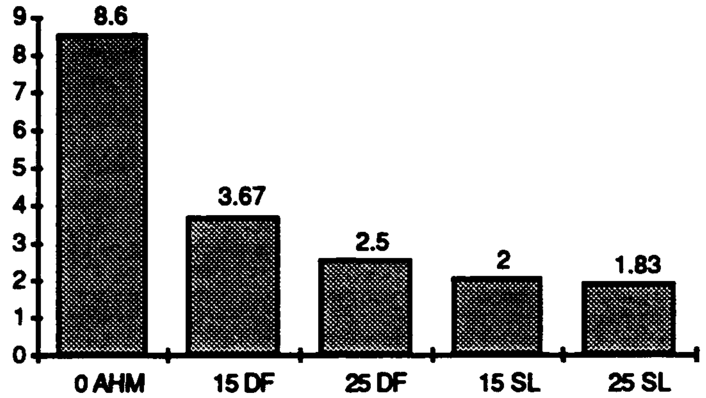


Figure 15. Mean Armor Kills by RWA--Offensive Scenarios

In Figure 15, the average number of kills in the 0 AHM case is 8.6. When AHMs were deployed, the average dropped to 2.5 (over all categories). This difference is significant well below the 1 percent level (based on a two-tailed test with a t-statistic equal to 3.45). On the other hand, no significant difference exists between the four categories in which AHMs are present. The relevant F-statistic equals 0.2.

The helicopter force would often be destroyed by the end of each trial in which AHMs were present. This high attrition rate appeared to hold whether or not AHMs destroyed RWA. Since OPFOR knew which trials had AHMs, it seems likely that the presence of AHMs caused the OPFOR player to fly the helicopters over routes that made them vulnerable to other antihelicopter weapons. Figure 16 displays the average number of helicopters destroyed by AHMs and by all weapon systems.

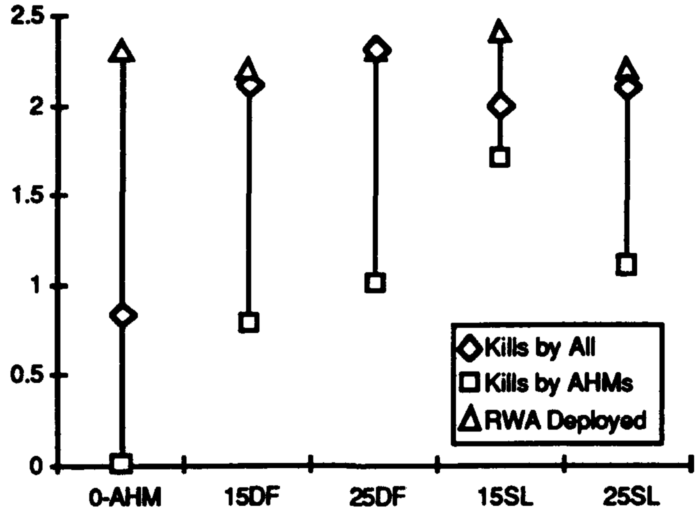


Figure 16. Mean RWA Killed--Offensive Scenarios

Air Defense Anti-Tank System (ADATS) and direct fire from Blue armor accounted for, on the average, 0.83 RWA kills per trial when AHMs were not deployed. When AHMs were deployed, ADATS and direct fire accounted for 1.03 RWA kills per trial. This difference is not statistically significant (at, say, the 0.05 level). However, when one considers that the ADATS and direct fire systems may have had, on the average, one less available RWA target due to attrition by AHMs, the difference of 0.2 kills per trials is magnified.

Table 12 describes the manner in which the exchange ratio varies with the number of RWA destroyed. The table shows the exchange ratio as a function of RWA destroyed by AHM, and by all systems combined. Focusing on the trials in which two RWA were killed, the exchange ratio was more favorable for Blue when AHMs destroyed both RWA than cases in which some were destroyed by other agents. A likely explanation for this is that AHMs tended to strike RWA early in the encounters, generally before the RWA could engage the Blue armor. ADA kills could occur early or late, and direct fire from armor vehicles almost always occurred during the engagement. (With the exception of helicopter crashes, two of which occurred in the 86 tests, there were no other means of destroying RWA).

Table 12. Exchange Ratios Versus Number of RWA Destroyed

Category	0 RWA Killed	1 RWA Killed	2 RWA Killed	3 RWA Killed
All Agents	0.11	0.32	0.84	1.34
0 AHM Kills	0.11	0.32	0.70	-
1 AHM Kills	-	-	0.71	1.59
2 AHM Kills	-	-	1.44	1.17

b. Defensive Scenarios

Figure 17 shows armor kills by RWA in the defensive scenarios. Again, these are based on Table-Logger files. On three occasions, the Table-Logger was unavailable; hence the data are based on 37 tests.

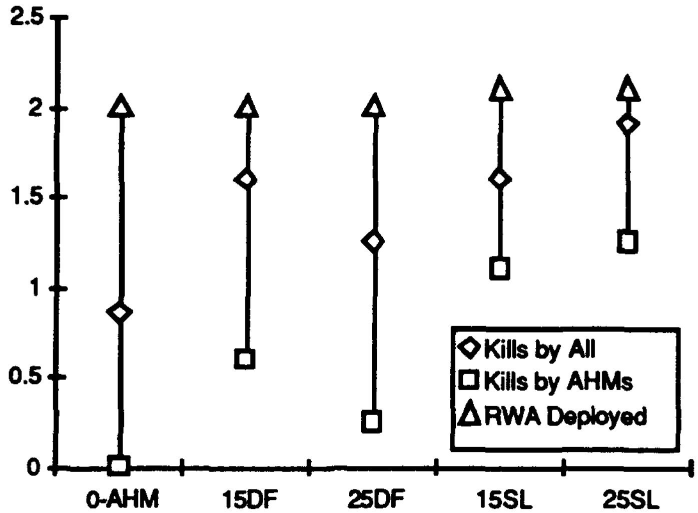


Figure 17. Mean RWA Killed--Defensive Scenarios

With the exception of the 25 DFAHM case, RWA killed approximately three Blue armor vehicles when AHMs were deployed. The exceptional case appears to be closely tied to the relatively low number of RWA destroyed (especially by AHMs) in the 25 DFAHM trials (see Figure 18 below). The average number of kills without AHMs was 7.17 and 3.1 with AHMs. The applicable t-statistic well below the 1 percent level. The F-statistic indicates no difference among the cases in which AHMs are present.

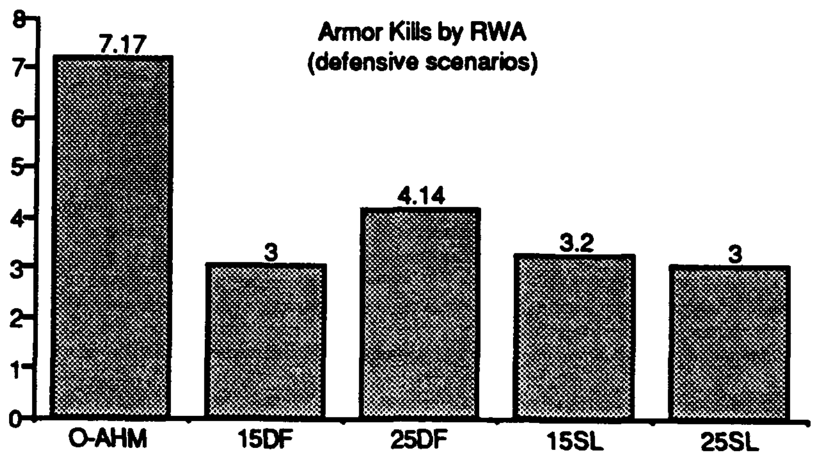


Figure 18. Mean Armor Kills by RWA--Defensive Scenarios

As in the offensive scenarios, substantially higher numbers of RWA were destroyed in trials in which AHMs were present compared to those in which AHMs were not played. This appears to be true even in the 25 DFAHM case. Here, only 0.25 RWA are destroyed by AHMs per trial; yet the total RWA destroyed is, on average, about 0.39 greater than the 0 AHM case.

Exchange ratio as a function of RWA destroyed behaves in a more dramatic manner in the defensive scenarios than in the offensive scenarios (Table 13). In particular, the effect of AHMs destroying two RWA is considerably greater. A possible explanation is that, once all the RWA are eliminated (2 RWA were flown in 38 of the 40 defensive trials), Blue armor generally faired well against their OPFOR counterparts. With fewer Blue vehicles to lose in the defensive scenarios (at most two platoons could populate the denominator of the exchange ratio), larger exchange ratios occur.

Table 13. Exchange Ratios as a Function of RWA Destroyed (Defensive Scenarios)

Category	0 RWA Killed	1 RWA Killed	2 RWA Killed	3 RWA Killed
All Agents	0.73	0.89	2.71	-
0 AHM Kills	0.73	0.92	1.92	-
1 AHM Kills	-	0.78	2.07	-
2 AHM Kills	-	-	5.68	-

3. AHM Launches, Hits, and Kills

Figures 19 and 20 show the number of AHM launches, hits, and kills. It should be pointed out that, early in the trials, parameters were set that forced the SLAHMs to attempt to intercept RWA whose points of closest approach were as far away as 250 meters. The low Pk at this range caused "wasted shots." When this parameter was reset so that intercepts were attempted only if the target vehicle was expected to pass within 180 meters, SLAHM performance was enhanced. The longer maximum engagement range was used in 5 of the 16 offensive SLAHM trials and in 6 of the 18 defensive trials.

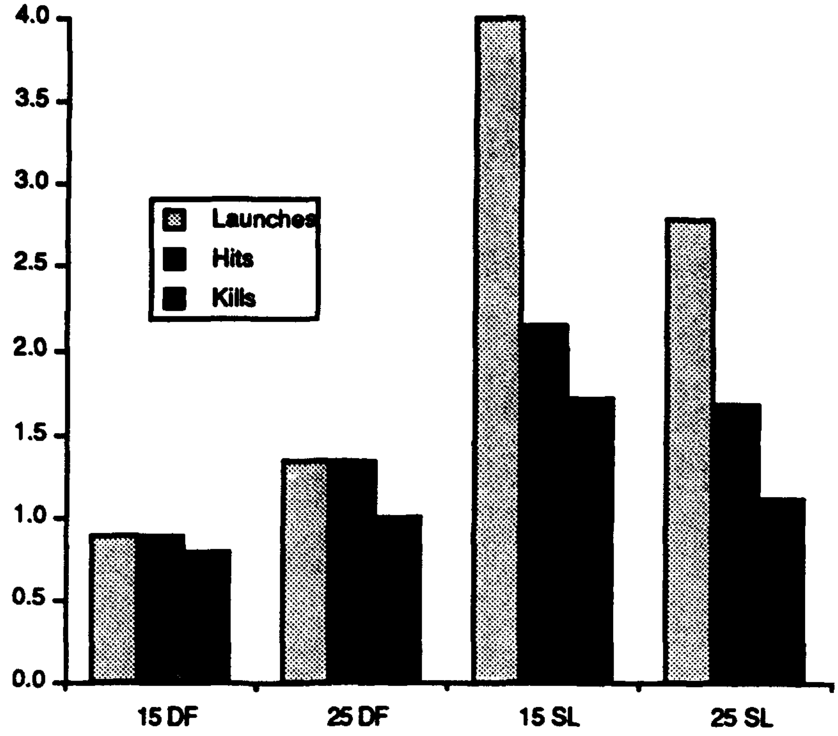


Figure 19. Mean AHM Performance--Offensive Scenarios

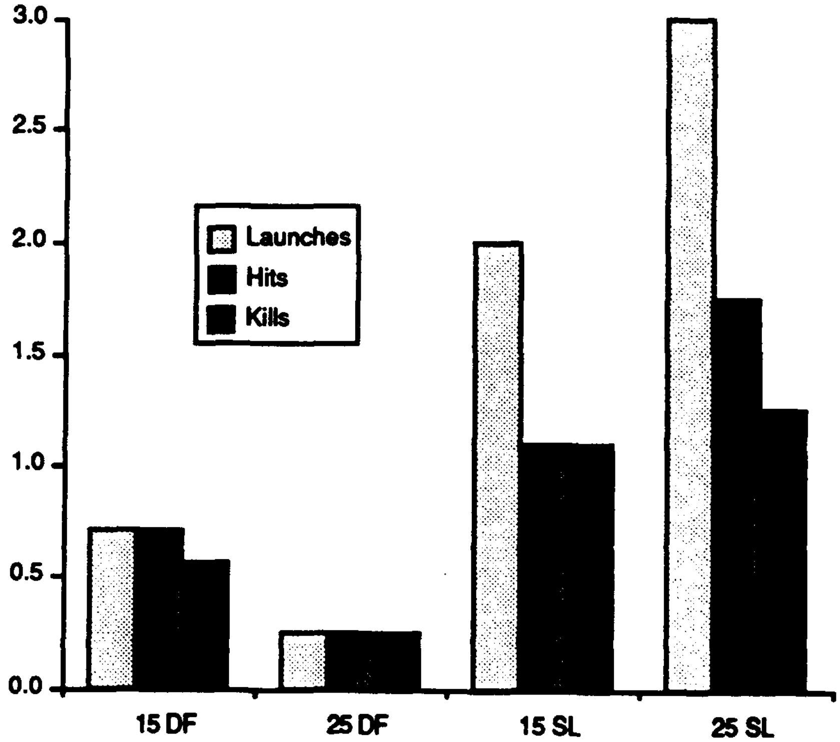


Figure 20. Mean AHM Performance--Defensive Scenarios

As noted above, by design, the DFAHMs never missed. On the other hand, the SLAHMs had to fly out and intercept the oncoming helicopter. Helicopter maneuvers, as well as other factors, made this a less certain event. The frequency over <u>all</u> trials of hits given a SLAHM launch was 55 out of 97, or approximately 57 percent. The total of DFAHM hits (and launches) was 27 and the total kills was 22 with 5 overkills. The corresponding figures for SLAHMs were 55 hits, 43 kills, and 12 overkills. In every trial, the number of individual helicopters hit by AHMs is equal to the number of helicopters killed by AHMs.

B. DENSITY OF MINEFIELDS

Mines were placed at the discretion of the Blue player. Both DFAHMs and SLAHMs tended to be placed in linear arrays along or across anticipated helicopter routes or in lattices within areas from which RWA attacks were expected.

Spacing, defined as distance to nearest neighbor, differed from case to case. In the 67 cases in which AHMs were played (offensive and defensive scenarios combined), 250 meter spacing was selected 30 times. In the 33 trials in which DFAHMs were deployed, they were spaced 250 meters apart 13 times, less than 250 meters 15 times, and more than 250 meters only 5 times. SLAHMs were deployed in 34 trials, 17 times at 250 meters apart, less than 250 meters 7 times, and more than 250 meters 10 times.

Figures 21 and 22 relate AHM performance to spacing. The first shows the mean RWA kills per trial by AHMs as a function of spacing. The second shows the number of RWA kills per 100 mines deployed, also as a function of spacing. These figures illustrate that spacing can significantly affect AHM performance through overkills and coverage gaps created by AHM firings. However, because the appropriate choice of minefield configuration will depend on the application (areas to be covered, expected helicopter tactics, desired effects, etc.) much more work will be required before minefield emplacement algorithms can be specified.

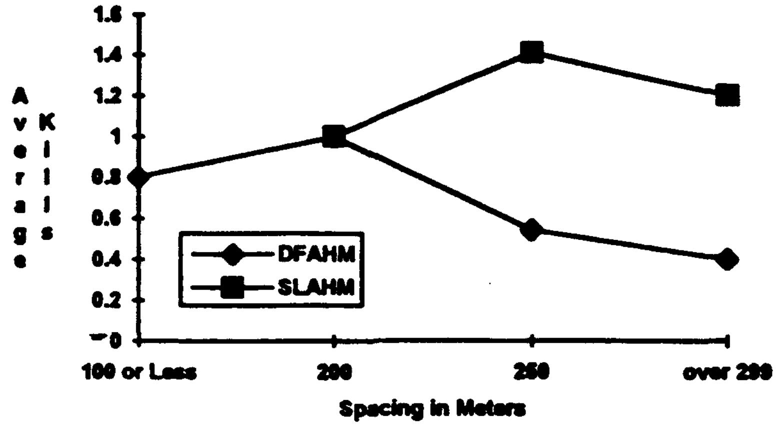


Figure 21. RWA Kills by AHMs per Trial Versus Spacing

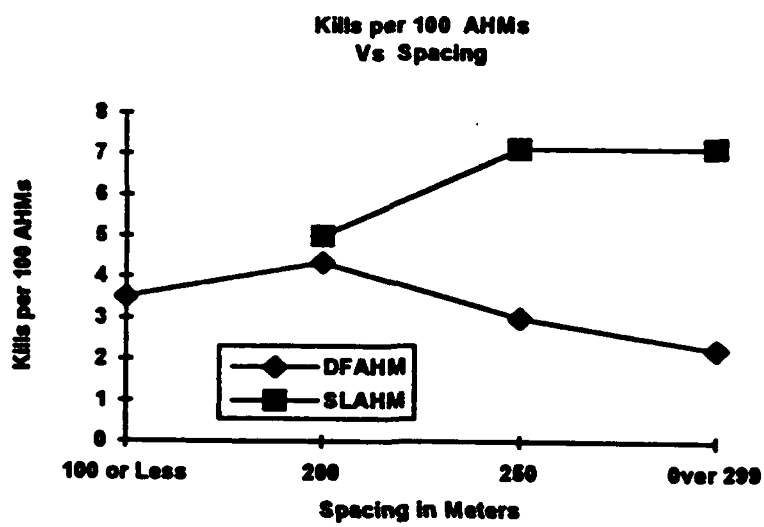


Figure 22. RWA Kills by AHM per 100 Mines Versus Spacing

Overall, for these particular scenarios, a total of 655 DFAHMs were deployed over the course of 33 trials. They accounted for 22 RWA kills, or roughly 3.4 kills per hundred deployed. Over the 34 trials, 652 SLAHMs were deployed. They accounted for 43 RWA kills, or approximately 6.6 RWA per hundred.

C. COST BENEFIT ANALYSES

This section examines two ways of assessing the cost-benefit ratio of AHMs in the trials that were conducted.

1. Cost Per Kill

The first cost benefit is the cost of destroying one OPFOR armor vehicle without AHMs and with AHMs. Cost per kill is calculated as a ratio; the numerator is the cost of Blue vehicles lost plus the cost of AHMs deployed or expended, and the denominator is the number of OPFOR vehicles killed. This ratio is calculated separately in the offensive and defensive scenarios.

Unit procurement costs for the various systems appear in Table 14. Unit costs of Blue armor systems are based on procurement funding in the early 1990s; unit costs for OPFOR armor are estimated at two-thirds the costs of similar Blue systems. Unit costs for AHMs were provided by the manufacturers and represent estimates based on procurement estimates, but do not include such ancillary costs as transportation, logistics, and operations.

Table 14. Unit Procurement Costs

Hardware Item	Unit Cost ($K)
M1	3600
M2	1100
T72	2400
BMP	733
DFAHM	7
SLAHM	15

Cost analyses are based on the number of OPFOR armor vehicles lost over the course of the offensive and defensive trials. Comparisons are made between the cases in which no AHMs are deployed and those in which DFAHMs or SLAHMs are deployed. Table 15 shows, for each type of scenario played, the total number of Blue armor vehicles

expended (destroyed), the total number of AHMs deployed, armor lost and AHMs deployed, and the total cost to Blue of these kills of OPFOR armor. Tables 16 and 17 show and compare the cost per kill to Blue in cases in which AHMs are deployed with the "base case" in which no AHMs are deployed. When AHMs are deployed, costs are computed in two ways: first, by counting all AHMs deployed as expended (Table 16) and, second, by counting only those AHMs that were fired or launched (Table 17).

Table 15. Total Procurement Cost of Blue Vehicles Lost and AHMs Deployed--Separately for Offensive and Defensive Scenarios

Cost	Offensive Scenario Trials			Defensive Scenario Trials		
Component	0 AHMs	DFAHM	SLAHM	0 AHMs	DFAHM	SLAHM
M1 Lost	85	81	48	27	39	39
M2 Lost	74	68	65	28	44	50
AHMs Deployed	0	350	315	0	305	337
Cost ($M)	387.4	368.85	249.04	128	190.94	200.46

Table 16. Cost Per Kill--Separately for Offensive and Defensive Scenarios (All Deployed AHMs Are Lost)

Measure	Offensive Scenario Trials			Defensive Scenario Trials		
	0 AHMs	DFAHM	SLAHM	0 AHMs	DFAHM	SLAHM
Kills	49	112	104	39	142	194
$M/Kill	7.91	3.29	2.39	3.28	7.34	1.03
percent Saved		58.34 percent	69.71 percent		59.03 percent	68.52 percent

Table 17. Cost Per Kill--Separately for Offensive and Defensive Scenarios (Only Launched AHMs Are Lost)

Measure	Offensive Scenario Trials			Defensive Scenario Trials		
	0 AHMs	DFAHM	SLAHM	0 AHMs	DFAHM	SLAHM
AHMs Launched	0	20	53	0	7	44
Cost ($M)	387.4	366.54	245.10	128	188.85	196.06
Kills	49	112	104	39	142	194
$M/Kill	7.91	3.27	2.36	3.28	1.33	1.01
percent Saved		58.61 percent	70.19 percent		59.48 percent	69.21 percent

Tables 16 and 17 indicate that, for each type of scenario played and for each method of tallying expenditures, DFAHMs produce savings of approximately 60 percent, while SLAHMs produce savings of approximately 70 percent when compared to the 0 AHM cases.

The unit cost of either type of AHM is very small compared to that of an armored vehicle. Hence, in these scenarios where AHMs prevent the loss of many Blue armored vehicles and thereby increase kills of OPFOR vehicles, costs per kill and percent savings over the base case are relatively insensitive to increases in mine cost. For example, doubling the price for the SLAHM reduces percent savings by less than 1 percent when counting all mines deployed as expended.

2. Marginal Return on Investment

Another economic measure of AHM worth is the marginal return on AHM investment (MROI). This is defined as the revenue generated per dollar invested. In terms of these exercises, marginal return would be the amount of money saved by Blue plus the amount of money lost by OPFOR for each dollar spent on expending AHMs.

Table 18 shows the average Blue and OPFOR losses for offensive and defensive trials in three cases: 0 AHMs, DFAHMs, and SLAHMs.

Table 18. Average Blue and OPFOR Losses

Force	Offense			Defense		
	0 AHMs	DFAHM	SLAHM	0 AHMs	DFAHM	SLAHM
BLUE						
M1	7.08	4.50	3.00	3.86	2.60	2.17
M2	6.17	3.78	4.06	4.00	2.93	2.78
OPFOR						
T72	2.42	3.44	3.69	3.29	4.93	6.39
BMP	1.67	3.33	2.81	2.29	4.53	4.39
HAVOC	0.83	2.22	2.06	0.86	1.40	1.72
Cases	12	18	16	7	15	18

Table 19 contains the average "return" to Blue over the 0 AHMs case. Again, return means the cost savings due to fewer Blue systems destroyed plus the estimated value of OPFOR systems destroyed.

From the bottom line of Table 19, the return on investment on these offensive scenarios is 115 for DFAHMs and 71 for SLAHMs. In the defensive scenarios, these values become 79 and 58, respectively. These computations treat all deployed mines as expended. If only those launched or fired are counted as expended, then the marginal returns are greater than 2,000 for DFAHMs and greater than 400 for SLAHMs for both scenario types.

Table 19. Return on Investment (ROI)

Force	Offense		Defense	
	DFAHM	SLAHM	DFAHM	SLAHM
Blue	(Savings)		(Savings)	
M1	9.3	14.7	4.53	6.06
M2	2.63	2.31	1.17	1.34
OPFOR	(Loss)		(Loss)	
T72	2.47	3.05	3.95	7.45
BMP	1.22	0.84	1.64	1.54
Total $M	15.62	20.90	11.29	16.42
AHM $M	0.136	0.296	0.142	0.281
MROI	115	71	79	58

D. PLAYER LEARNING

There were two primary players in the exercises and they varied the role (Blue or OPFOR) that each played. One of the two took part in all 86 trials. The other person was unavailable for 25 trials and a third player was introduced for these trials, primarily in the OPFOR role.

In the course of the 86 trials, various forms of learning took place. Operators became more familiar with the SAF operation and, as time progressed, were better able to control their units, especially, helicopters. Operators became more adept at synchronizing armor maneuvers, controlling helicopter speed and altitude, and guiding helicopters along the terrain to preselected positions.

In particular, the decision to change from flights of three helicopters to flights of two was the result of increased operator competence. Initially, operators were not able to maneuver helicopters precisely and keep them out of ADA line-of-sight or direct-fire range. Flights of three helicopters were necessary due to heavy RWA losses to ADA. After the first 15 trials (13 in Offense_1, and 2 in Defense_1) operators had become sufficiently competent at controlling the helicopters to make a third RWA unnecessary (based on performance in the 0 AHM cases), and the decision was made to switch to flights of two helicopters.

Mine-related learning also took place, primarily related to emplacement/engagement strategy and mine avoidance. (Mine simulator operations are transparent to the operator once the field is chosen, emplaced, and activated.) For example, helicopter "pilots" learned to fly as low as possible (often between 2 and 5 meters above the terrain) to minimize

exposure to direct fire mines as well as ADA. The Blue commander learned the value of placing mines in successive (parallel) rows perpendicular to the expected paths of the HAVOCs to minimize the "mine clearing" capability of a single helicopter and also learned the value of restricting the engagement range of SLAHMs to increase their hit probabilities.

Regarding this last point, in the first 11 trials using sublet mines, engagement rules were such that SLAHMs were launched at any helicopter whose closest approach was expected to be within 250 meters. Under these conditions, the probability of hit given a launch was unsatisfactorily low (0.3). After these first 11 trials, in which 47 SLAHM were launched, engagement rules were changed so that only those RWA expected to pass within 180 meters of a mine were engaged. In the subsequent 23 trials in which 50 SLAHM were launched, hit given a launch increased to 0.82. (Over all cases, the ratio of hits to launches for SLAHMs was 0.57.) As a result of this change, exchange ratios and the difference between Blue losses and OPFOR losses increased dramatically. These performance changes are summarized in Table 20.

Table 20. Comparison of 250-Meter and 180-Meter SLAHMs (Exchange Ratios and Loss Differences)

Offensive Scenarios

Range (m)	Trials	AHM kills	X-Ratio	Loss Diff.
180	11	1.45	1.15	- 0.91
250	5	1.2	0.59	+ 3.80

Defensive Scenarios

Range (m)	Trials	AHM kills	X-Ratio	Loss Diff.
180	12	1.25	2.70	- 7.08
250	6	1.0	1.51	-3.33

Combined Scenarios

Range (m)	Cases	AHM kills	X-Ratio	Loss Diff.
180	23	1.35	1.81	- 4.13
250	11	1.09	1.01	- 0.09

While the variations in exchange ratio and armor loss differences may be dramatic, it should be kept in mind that RWA deployment decreased from 2.6 per trial (combined) when the longer range criterion was in effect to 2.0 per trial afterwards. Although the 180 meter SLAHMs killed more RWA per trial, the reduction in flight size may have had more of an effect on exchange ratios and loss differences than increased mine effectiveness.

Other effects of learning are quantified in Tables 21 and 22 below. There, trials are grouped according to type of AHM and type of scenario (offensive or defensive). Within

each group, trials were ordered chronologically. Exchange ratios and helicopter kills by AHMs are tabulated for the first and second halves of each trial group. The number of trials in each cell is shown in parentheses. For the sake of completeness, a combined (offense and defense) performance column is included for each mine type.

Table 21. Direct Fire Mines

Half	X-Ratio (Offense)	AHM Kills (Offense)	X-Ratio (Defense)	AHM Kills (Defense)	AHM Kills (combined)
1st	0.97 (9)	1.22 (9)	2.05 (8)	0.63 (8)	0.94 (17)
2nd	0.59 (9)	0.56 (9)	1.41 (7)	0.14 (7)	0.38 (16)

Table 22. Sublet Launched Mines

Half	X-Ratio (Offense)	AHM Kills (Offense)	X-Ratio (Defense)	AHM Kills (Defense)	AHM Kills (combined)
1st	0.75 (8)	1.38 (8)	1.94 (9)	1.11 (9)	1.18 (17)
2nd	1.14 (8)	1.38 (8)	2.46 (9)	1.22 (9)	1.35 (17)

Table 23. Mean RWA Deployment

Half	DFAHM (offense)	SLAHM (offense)	DFAHM (defense)	SLAHM (defense)	DFAHM (combined)	SLAHM (combined)
1st	2.6	2.6	2.0	2.2	2.3	2.4
2nd	2.0	2.0	2.0	2.0	2.0	2.0

It appears from Table 21 that the OPFOR commanders improved their ability to avoid DFAHMs considerably from the first to the second half of the exercise. Exchange ratios drop 40 percent in the offensive scenarios and 30 percent in the defensive scenarios. On the other hand, Blue commanders appeared to improve their ability to deploy sublet-launched mines over time, by using low density deployment of SLAHMs at potential RWA firing positions in conjunction with an "absorbing barrier" deployment. Blue may also have realized that DFAHMs were more effective at potential firing positions where RWA would pop-up. Exchange ratios jumped 50 percent in the offensive scenarios and 25 percent in the defensive scenarios between the first and the second halves of the exercises when SLAHMs were deployed. (As noted in Section I.C, the first half of the SLAHM trials were heavily concentrated in one location and the second half in the other location, so that learning and location effects for SLAHM are somewhat confounded.)

This study represents the first attempt to explore the assessment of AHMs using SIMNET. The learning that took place during the study has important methodological implications with respect to both the interpretation of the results of the study and the conduct of SIMNET studies in general. It may also have developmental and operational implications.

E. LOCATION DEPENDENCY

Tables 24 and 25 summarize scenario effects. They contain exchange ratios and mean armor loss differences for DFAHMs and SLAHMs when the 15 mine and 25 mine cases are combined.

Table 24. Exchange Ratios (Red + Blue) Versus Scenario

Mine	Offense 1	Defense 1	Offense 2	Defense 2
DFAHM	1.18	1.88	0.49	1.54
SLAHM	0.81	1.93	1.04	2.61

Table 25. Armor Loss Differences (Blue - Red) Versus Scenario

Mine	Offense 1	Defense 1	Offense 2	Defense 2
DFAHM	-1.0	-4.63	5.88	-3.14
SLAHM	1.38	-4.73	-0.25	-7.57

Some outcomes were location dependent. For example, exchange ratios in those trials using DFAHMs dropped from 1.18 under Offense 1 to 0.49 under Offense 2. Accordingly, the mean difference in armor losses increased from -1.0 to 5.88, a change that is significant at about the two percent level. There are other apparent location effects, e.g., the drop in armor loss differences from SLAHM Defense 1 to Defense 2, but none of these is statistically significant.

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Appendix A
GLOSSARY

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GLOSSARY

ADA	air defense artillery
ADATS	Air Defense Anti-Tank System
AHM	antihelicopter mines
BMD	infantry fighting vehicle (Soviet)
CPA	closest point of approach
DF	direct fire
EFP	explosively formed penetrator
FAADS	forward area air defense system
IDA	Institute for Defense Analyses
IFV	infantry fighting vehicle
IR	infra-red
km	kilometer
MROI	marginal return on investment
OPFOR	Opposition Force
PDU	protocol data unit
Pk	probability of kill
RWA	rotary wing aircraft
SAF	Semi-Automated Forces
SL	sublet launched
SMS	Smart-Mine Simulator
TOW	tub-launched, optically tracked, wire-guided

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Appendix B
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